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TECHNICAL NOTE

Experimental Investigation of the Effect of Process Parameters on the Surface Roughness in Finishing Process of Chrome Coated Printing Cylinders

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ABSTRACT

One of the challenges in the printing industry is the presence of extra lines in printing design. This problem is due to the improper surface roughness of carved cylinders. This research endeavors to specify and optimize the effective parameters on the surface roughness of chrome coated printing cylinders in the finishing process that is done using a finish star machine. Investigated parameters include lubricant volume, feed rate of machine head, emery feed rate, emery compressive force, emery vibration and peripheral speed. By performing some experiments designed by response surface methodology, suitable ranges for the parameters were determined using contour plots and desirability function approach. Results show that the head feed rate, peripheral speed of the part and emery force are the significant parameters on the surface roughness. Surface roughness decreases by reducing the head feed rate. By increasing the emery force up to ten kilogram, surface roughness increases but afterwards gradually decreases. The roughness decreases by increasing the peripheral speed of the part up to 40 m/min, but increases after this value. At last, suitable range and optimal value of the effective process parameters was achived for the desirable surface roughness that is between 0.32 to 0.37 micron.

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1. INTRODUCTION

Due to the development of technology and presence of a competitive market, importance of printing industry has increased. The main printing methods can be defined based on the physical characteristics of printing surface. Printing methods include letterpress, lithography and gravure. Mechanism of printing using the gravure method is shown in Figure 1.

In this method, printed sections are deeply engraved on a cylinder that is in the form of small cells. These cells are filled with ink and a thin metal blade called, doctor blade, cleans the regions without printing by passing through the cylinder. By passing the printed material, inks of the cells are transferred onto the film. Size of the engraved cells are generally in the range of

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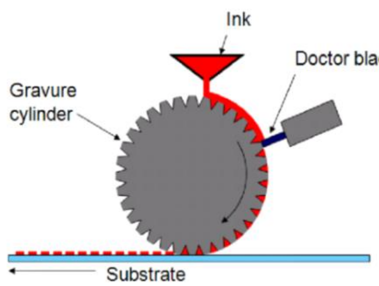

Figure 1. Printing by gravure cylinder

90 to 230 micron in width and 30 to 100 micron in height. Cylinder engraving machines have a precision of one micron. To perform finishing operations on the surface of the cylindrical parts depending on the required accuracy and surface roughness, there are different operations including lapping, grinding and sanding. There are several parameters that affect the quality of surface such as depth of cut, material hardness, the rotational speed of workpiece, grain size

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of grind, the number of machining pass, metal removal rate (MRR) and rotational speed of grind [1]. Among the grinding parameters, workpiece speed and the removal rate are very important because increase of these two parameters has a negative effect on the surface roughness [2]. In grinding process, lubricants are used to cool the grinding zone and cause to decrease the workpiece temperature and provide protection from environmental damage [3]. Limited studies have been reported on the surface finishing process of cylinderical parts. Thiagarajan et al. [4] used genetic algorithm for modelling and optimizing the grinding of cylindrical parts made of Al/Sic composite. Their results show that by increasing the surface roughness from 0.15 micron to 0.45 micron, the MRR increases almost ten times. Pal et al. [5] minimized the surface roughness of EN24 and EN31 steels using Taguchi method. Their investigated parameters were material hardness, part speed and graining of the grind. They found that the surface roughness decreases with increasing the hardness. George et al. [6] experimentally investigated the effect of process parameters including depth of cut, part speed and hardness on surface roughness via Taguchi method. They reported that the surface roughness of 0.47 micron can be achived at optimum levels of parametes. Ganesan et al. [7] studied the effect of process parameters including depth of cut, feedrate and part speed on the surface roughness of SS304 steel using Taguchi method. They concluded that proper surface roughness is due to good level of parameters. Kumar et al. [8] investigated the grinding process of EN24 steel by Al_2O_3 grind and using response surface methodology (RSM). Their parameters were table feed rate, grind speed and part speed. The rsults showed that there was a good agreement between predicted values and experiments. Sohal et al. [9] studied the effect of table speed, depth of cut and removal rate on the surface roughness of EN24 and EN353 steels. They could decrease the surface roughness to 0.38 micron. Manickam et al. [10] studied the effect of part speed, depth of cut and the number of machining pass on the surface roughness of OHNS steel. They found that the machining pass is an important parameter in grinding of OHNS steel.

Finishing is the final process that is used in manufacturing of the printing cylinders. There are not enough data on changing the process parameters to achieve the desired surface roughness that has small tolerance. Moreover, the effect of process parameters on the surface roughness of chrome coated printing cylinders using the finish star machine has not been yet reported. So the goal of this research is to specify the effective parameters on the surface roughness of chrome coated printing cylinder in finishing process and optimization of the process parameters to achieve desired surface roughness.

2. MATERIALS AND EXPERIMENTS EQUIPMENT

Printing cylinders are generally used in sizes between 600 and 1400 mm length and diameters from 100 to 250 mm. Figure 2 shows the processes that is used in manufacturing of the printing cylinders. According to this figure, the cylinders are coated in two steps with copper and chrome. In coating with copper, a copper with a purity of 99% is used that its oxygen and phosphorus are below 5 ppm. For coating with the chrome, CR1000 type is used. Finishing operations are performed on a finish star machine model p-1814 cu/cr made in Germany in 2010. Figure 3 shows the studied printing cylinders with a length of 650 mm. The initial cylinder and its flanges are made of St37 steel.

Part positioning on the finish star machine is shown in Figure 4. As it can be seen, the workpiece is clamped between the two tailstocks. After part positioning, the cylinder rotates using a servo motor and then the head of the machine is moved towards the part. Afterward, a zone of the head that the emery is mounted on it starts to move and vibrate to part. After contacting of emery with the part and applying the desired force, the head starts to move via determined feed rate. Finishing process is performed using an sandpaper of 20 micron. This paper is made of a layer of polyester film with a thickness of 0.2 mm which aluminum oxide particles with twenty micron-sized particles are attached to it.

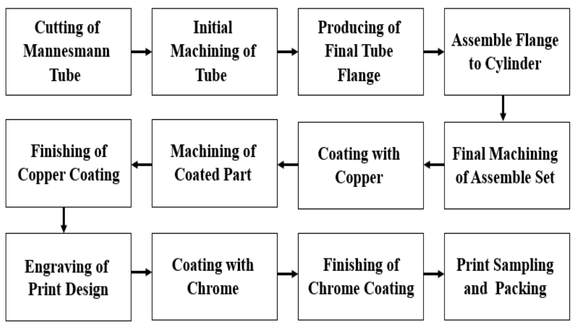


Figure 2. Manufacturing steps of the printing cylinders

Figure 3. Printing cylinders

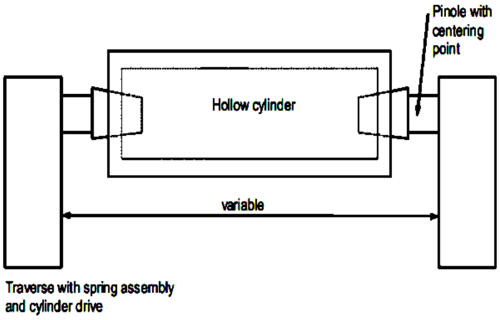


Figure 4. Part positioning on the finish star machine

Figure 5 shows the finish star machine during finishing of the cylinder. Surface roughness is measured using a Garant model 498850 H1 roughness mesuring device that is shown in Figure 6. This device is able to measure the surface roughness with an accuracy of 100 micron acording to Rz and Ra criterion. In the printing industry because of the sensitivity of the surface roughness, the Rz criterion is generally used.

3. DESIGN AND PERFORMING THE EXPERIMENTS

3. 1. Fractional Factorial Design of Screening Experiments

Due to the high number of process parameters, many experiments should be carried out for identifying the effective parameters on the surface roughness.

Figure 5. Finishing the printing cylinder by finish star machine

Figure 6. Measuring the surface roughness

In the present study, process parameters include lubricant volume, machine head feedrate, emery feed rate, emery compressive force, emery vibration and peripheral speed of the part were considered as input parameters. Each parameter is selected in two levels, according to data given in Table 1. If the experiments were performed via full factorial design, 64 experiments were needed (2^6=64). So fractional factorial design was used to reduce the number of experiments. Therefore, 32 experiments were designed using Minitab software [11] and then performed. Screening design of experiments with surface roughness (Rz) are given in Table 2.

3. 2. Design of Experiment by Response Surface Methodology

Response surface methodology (RSM) is used to estimate the functions describing the relationship among some influencing parameters and rsponse surface as the process outputs [12-13]. The most important aim of RSM is to use a series of designied experiments to achieve an optimal response. In many cases, a second-degree polynomial model is used in RSM as folllows [14].

$$y = \beta_0 + \sum_{i=1}^{k}(\beta_i x_i) + \sum_{i=1}^{k}(\beta_{ii} {x_i}^2) + \sum_i \sum_j (\beta_{ij} x_i x_j) + \varepsilon \tag{1}$$

where, y is the response, β_0 , β_i , β_{ii} , β_{ij} are unknown constant coefficients and x_i and x_j, denote the independent design variables, k is the number of the independent variables, and ε is the statistical error. The matrix notation of the regression model can be expressed as follow in which β_0, β_1,…, β_k are unknown constant coefficients.

TABLE 1. The range of input parameters

Parameter	Designation	Level	
		Min	Max
Lubricant value	L	0	1
Emery vibration (rpm)	O	500	990
Emery force (kg)	F	10	40
Head feed rate (mm/rev)	Cs	10	90
Emery feed rate (mm/min)	Tf	10	30
Peripheral speed (m/min)	V	20	100

TABLE 2. Screening design of experiments and outputs

Run no.	L	O	F	Cs	Tf	V	Rz (µm)
1	1	500	10	90	30	100	0.93
2	0	990	10	10	10	100	0.40
3	0	500	40	90	30	100	0.55
31	0	990	10	10	30	20	0.31
32	0	500	40	10	30	20	0.30

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{bmatrix} = \begin{bmatrix} 1 & x_{11} & x_{12} & \cdot & \cdot & \cdot & x_{1k} \\ 1 & x_{21} & x_{22} & \cdot & \cdot & \cdot & x_{2k} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ 1 & x_{n1} & x_{n2} & \cdot & \cdot & \cdot & x_{nk} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \beta_1 \\ \cdot \\ \cdot \\ \cdot \\ \beta_k \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_n \end{bmatrix} \quad (2)$$

If X and Y introduce variables matrix and responses respectively, the coefficients of β are as follows:

$$\beta = (X^T X)^{-1} XY \quad (3)$$

After screening design of experiments, it was found that head feed rate, peripheral speed and emery force were the significant parameters. So 20 experiments were designed and performed by central composite design (CCD) according to Table 3.

By analyzing and modeling the experiments, the goodness of the model (R^2) was obtained very low. Therefore, the screening experiments (32 tests) were combined with the CCD experiments (20 tests) at this stage. Overall, 52 experiments were used in modeling of surface roughness of printing cylinders by RSM.

4. RESULTS AND DISCUSSION

This paper investigates the effect of input parameters on the surface roughness of the printing cylinders in the finishing process using the finish star machine. Firstly, results of the screening experiments are discussed and then the results of RSM are presented.

4. 1. Results of Screening Experiments

To examine the effect of process parameters, analysis of variance (ANOVA) technique is used. Figure 7 shows the normality of data distribution for screening experiments. Distribution points around the diagonal line represents a normal distribution of data. The results of the ANOVA using F-test are presented in Table 4. As it can be seen, the P-value of F (emery force) and Cs (head feedrate) is less than 0.05. As a result, these two parameters are significant. Also the P-value of Cs×V (intraction effect between head feed rate and peripheral speed) is less than 0.05. It should be remembered that the P-value of V is 0.07, this parameter is almost significant.

TABLE 3. Initial RSM design of experiments and outputs

Run no.	F	Cs	V	Rz (μm)
1	15	70	40	0.32
2	41.8	50	60	0.37
3	25	50	60	0.35
19	25	16.3	60	0.39
20	25	50	60	0.37

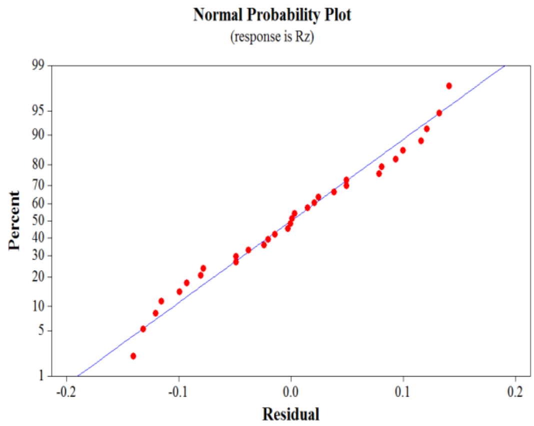


Figure 7. Normal distribution plot for screening tests

TABLE 4. ANOVA table for screening experiments

Source	DF	SS	MS	F	P
Main effects	6	2.21194	0.36866	17.76	0.000
L	1	0.01403	0.01403	0.68	0.430
O	1	0.430	0.01853	0.89	0.367
F	1	0.20963	0.20963	10.10	0.010
Cs	1	1.88665	1.88665	90.88	0.000
Tf	1	0.00008	0.00008	0.00	0.952
V	1	0.08303	0.08303	4.00	0.073
2-Way Interactions	15	0.49292	0.03286	1.58	0.234
L×O	1	0.05200	0.05200	2.50	0.145
L×F	1	0.00003	0.00003	0.00	0.971
L×Cs	1	0.01665	0.01665	0.80	0.392
L×Tf	1	0.05363	0.05363	2.58	0.139
L×V	1	0.00525	0.00525	0.25	0.626
O×F	1	0.00525	0.00525	0.25	0.626
O×Cs	1	0.02820	0.02820	1.36	0.271
O×Tf	1	0.06570	0.06570	3.16	0.106
O×V	1	0.01320	0.01320	0.64	0.444
F×Cs	1	0.06570	0.06570	3.16	0.106
F×Tf	1	0.00070	0.00070	0.03	0.858
F×V	1	0.00003	0.00003	0.00	0.971
Cs×Tf	1	0.00578	0.00578	0.28	0.609
Cs×V	1	0.17553	0.17553	8.45	0.016
Tf×V	1	0.00525	0.00525	0.25	0.626
Residual error	10	0.20761	0.02076		
Total	31	2.91247			

So F, Cs and V were considered as input parameters in RSM experiments. Figure 8 shows the main effect plots of these three parameters. It is observed that by increasing the Cs from 10 to 90 mm, the surface roughness increases approximately from 0.34 to 0.8 micron. By increasing F from 10 to 40 kg, surface roughness decreases from about 0.65 to 0.50 micron. By increasing V from 20 to 100 mm/min, surface roughness reduces of about 0.60 to 0.50 micron. Figure 9 shows the interaction effect between Cs and V. It is seen that by increasing V from 20 to 100 mm/min (Cs in 10 mm/rev) surface roughness increases slightly but in Cs of 90 mm/rev, surface roughness significantly decreases by increasing V. The goodness of the model (R^2) can be calculated as Equation (4) in which y_i is the objective function value from the model, $\hat{y}_i$ is the real value and y is the average value. This value for screening experiments was obtained 92.87% that is favorable.

$$R^2 = \frac{\sum (y_i - \hat{y}_i)^2}{\sum (y_i - \bar{y}_i)^2} \quad (4)$$

4. 2. Results of RSM Experiments Figure 10 shows the normal probability plot for the RSM experiments. It is seen that the data have a normal distribution. The ANOVA results are presented in Table 5. Final model for Rz based on input parameters was obtained as Equation (5) that is based on actual factors. Also predicted responce versus actual response for 52 experiments is shwon in Figure 11. The goodness of model for RSM experiments was obtained 86.87%.

$$\begin{aligned} R_z &= 0.311368 - 0.00407971\,F + 0.00174493\,C_s \\ &+ (8.21\times10^{-5})V + (1.09\times10^{-4})F^2 \\ &+ (8.006\times10^{-5})C_s^2 + (1.82\times10^{-5})V^2 \\ &-(7.49\times10^{-5})FC_s - (4.08\times10^{-5})VF \\ &-(4.67\times10^{-5})VC_s \end{aligned} \quad (5)$$

Figure 12 shows the response surface of Rz versus feedrate (Cs) and emery force (F), Cs and peripheral speed (V) and V and F, respectively. As it can be seen (12.a), generally increasing the Cs leads to increase the Rz. Effect of the F on the surface roughness is not consederable in this figure.

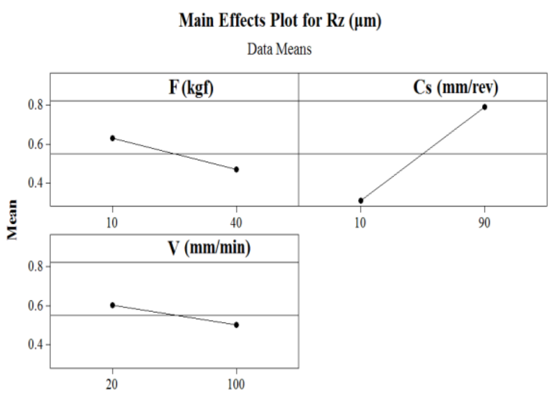


Figure 8. Main effect of three parameters on surface roughness

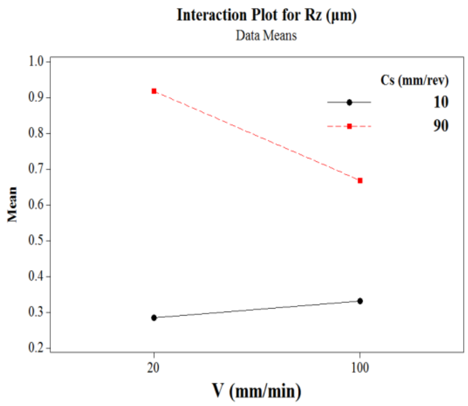


Figure 9. Interaction effect of V and Cs on surface roughness

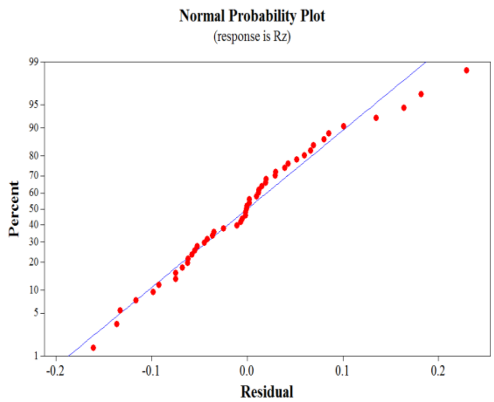


Figure 10. Interaction effect of V and Cs on surface roughness

TABLE 5. ANOVA table for RSM experiments

Source	DF	SS	MS	F	P
Regression	9	2.70153	0.30017	17.79	0.000
Linear	3	2.01881	0.67294	39.88	0.000
F	1	0.18081	0.18081	10.71	0.002
Cs	1	1.77743	1.77743	105.32	0.000
V	1	0.06057	0.06057	3.59	0.065
Square	3	0.44087	0.14696	8.71	0.000
F × F	1	0.00217	0.00217	0.13	0.722
Cs × Cs	1	0.03932	0.03932	2.33	0.134
V × V	1	0.00456	0.00456	0.27	0.606
Interaction	3	0.24185	0.08062	4.78	0.006
F × Cs	1	0.06276	0.06276	3.72	0.061
F × V	1	0.00001	0.00001	0.00	0.982
Cs × V	1	0.17908	0.17908	10.61	0.002
Residual error	42	0.70879	0.01688		
Total	51	3.41031			0.000

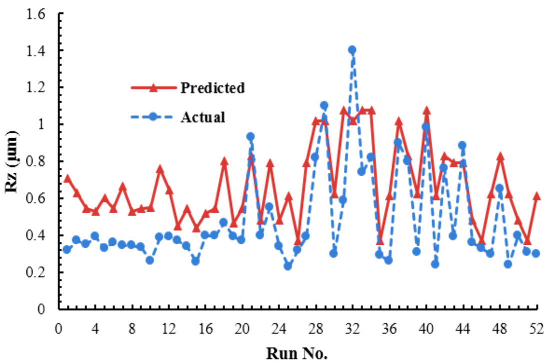
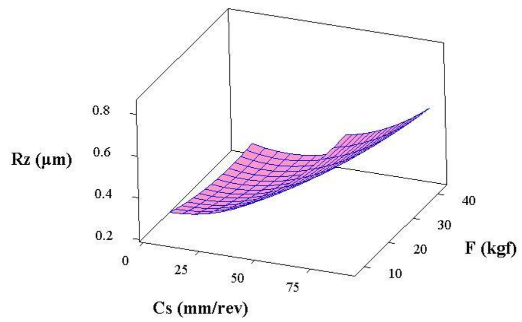
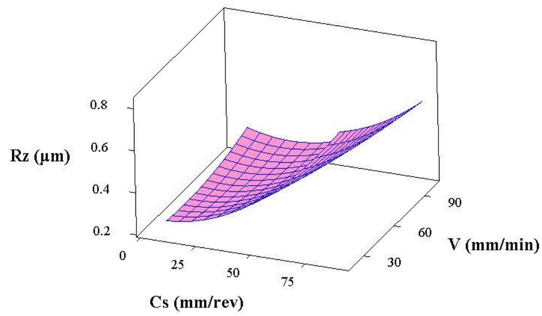


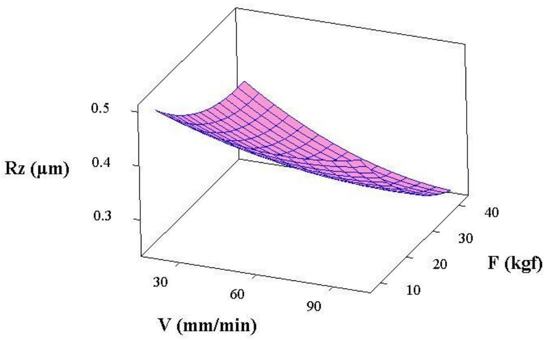
Figure 11. Predicted responce versus actual response for 52 experiments



(a)



(b)

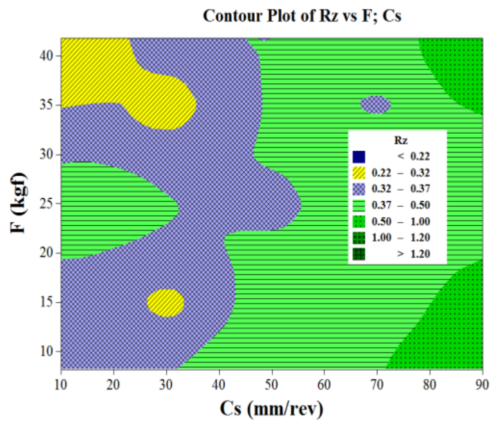


(c)

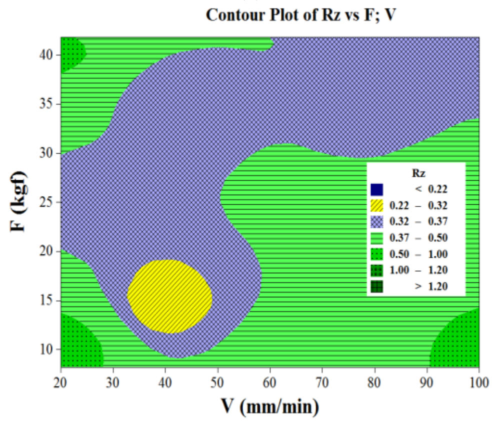
Figure12. Response surface versus (a). Cs and F (b). Cs and V (c). V and F

Roghness is decreesed by increasing the V and F. In high values of V and F, surface roughness is minimized (12.c). Also surface roughness decreases by reducing the Cs. Effect of the V on Rz is not considerable (12.b).

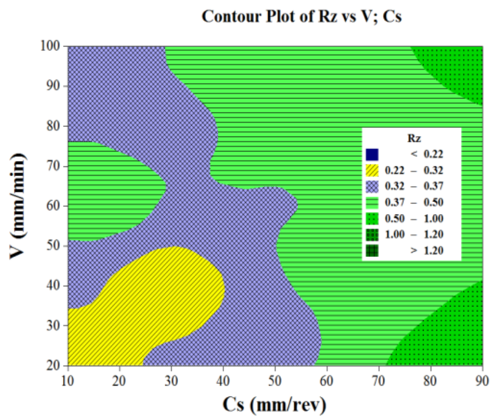
In finishing process of printing cylinders, the optimal range of parameters is necessary for the surface roughness. On the other hand, these ranges can not be achieved from response surfaces. So, contour plots was used to determine the optimal range of input parameters as Figure 13. Nominal surface roughness generally used for printing cylinders is between 0.32 to 0.37 micron based on Rz. Violet zones is suitable ranges for the process parameters.



(a)



(b)



(c)

Figure13. Contour plot for (a). F and Cs (b). F and V (c). V and Cs

For optimization of the process parameters and achieving an optimal point, desirability function approach was used. In this method optimization is performed using desirability function. For a problem that the target (T) is located between the upper (U) and lower (L) limits, desirability function is calculated as follow:

$$d=\begin{cases} 0 & y<L \\ \left(\dfrac{y-L}{T-L}\right)^{r_1} & L\le y\le T \\ \left(\dfrac{U-y}{U-T}\right)^{r_2} & T\le y\le U \\ 0 & y>U \end{cases} \qquad (6)$$

where, y is the response, r_1 and r_2 are weights of the desirability function for ranges $L \le y \le T$ and $T \le y \le U$, respectively. Then desirability function is optimized using reduced gradient method [15]. Optimization was done for the target value Rz=0.345 that is middle of the suitable range between 0.32 and 0.37. Optimal value of the parameters and the variation of response versus the variables are shown in Figure 14. Variation diagrams show that Cs has more effect on the response function. Optimal condition is F=22.93 kg, Cs=42.23 mm/rev and V=33.36 mm/min. In this condition Rz is predicted as 0.345 micron.

5. CONCLUSIONS

In this research, effect of the process parameters on the surface roughness of printing cylinders in the finishing process was investigated. Parameters include lubricant volume, machine head feed rate, emery feed rate, emery compressive force, emery vibration and peripheral speed of the part. Firstly, by design and performing the screening experiments it was specified that the machine head feed rate, emery compressive force and peripheral speed of the part are the significant parameters. In the second stage, the process were modeled and optimized using the response surface methodology. Results show that the surface roughness decreases about 0.46 micron by reducing the head feed rate. By increasing the emery force up to 10 kg, surface roughness increases, but afterwards gradually decreases. In addition, the roughness decreases by increasing the peripheral speed of the part up to 40 m/min, but increases after this value. Using the contour plots, suitable range of the effective parameters was achived for the nominal surface roughness generally used for the printing cylinders that is between 0.32 to 0.37 micron. Also using the desirability function approach, optimal condition for the process parameters was achieved that in this condition surface roughness (Rz) is predicted to be 0.345 micron.

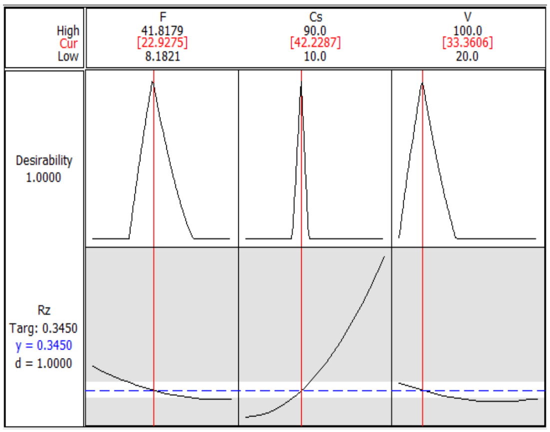


Figure14. Optimal value of the parameters and variation of response versus the variables

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Experimental Investigation of the Effect of Process Parameters on the Surface Roughness in Finishing Process of Chrome Coated Printing Cylinders

TECHNICAL NOTE

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چکیده

یکی از مشکلات موجود در صنعت چاپ با سیلندر چاپ حکاکی شده، وجود خطوط اضافه در چاپ یا کم‌رنگ و پررنگ بودن طرح چاپی می‌باشد که این مشکل عمدتا ناشی از زبری سطح نامناسب سطح سیلندر چاپ می‌باشد. در این پژوهش تلاش شده است تا عوامل تاثیرگذار بر زبری سطح سیلندرهای چاپ با پوشش کروم در فرآیند پرداخت‌کاری با استفاده از دستگاه فینیش استار شناسایی و بهینه‌سازی شود. پارامترهای مورد مطالعه شامل مقدار روانکار، میزان پیشروی هد دستگاه، میزان پیشروی سنباده، نیروی فشاری سنباده، میزان ارتعاش سنباده و سرعت محیطی قطعه‌کار چاپ می‌باشد. با انجام تجربی آزمایش‌های طراحی شده با روش رویه پاسخ، محدوده مناسب پارامترها برای زبری مطلوب با استفاده از نمودارهای کانتوری و روش تابع مطلوبیت بدست آمد. نتایج نشان می‌دهد که پارامترهای سرعت پیشروی هد، سرعت محیطی و نیروی سنباده سه عامل تاثیرگذار می‌باشند. با کاهش میزان پیشروی، زبری سطح کاهش می‌یابد. با افزایش نیروی سنباده تا ده کیلوگرم زبری سطح افزایش ولی با تجاوز از ده کیلوگرم زبری سطح به تدریج کاهش می‌یابد. همچنین با افزایش سرعت محیطی تا چهل متر بر دقیقه، زبری سطح کاهش می‌یابد ولی بعد از آن افزایش می‌یابد. محدوده مناسب و مقدار بهینه پارامترهای مؤثر، برای زبری سطح مطلوب که بین ۰/۳۲ تا ۰/۳۷ میکرون است استخراج شد.

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